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THE PRESSURE BUMP INSTABILITY IN VERY LARGE COLD BORE STORAGE RINGS

Peter Limon
Fermi National Accelerator Laboratory*
P.O.Box 500
Batavia, Illinois 60510

Abstract

Calculations have been done to estimate the circulating current necessary to induce the onset of a pressure bump instability in a cold bore storage ring. For a wide range of storage ring parameters, the instability threshold current is more than an order of magnitude higher than the operating current.

I. Introduction

The pressure bump instability is a phenomenon due to the ionization of gas molecules by the circulating beam. The ions are accelerated to the beam tube wall by the electrostatic potential of the beam, where they may knock out other molecules which in turn are ionized. If the beam current is sufficiently high and the number of molecules desorbed by each ion large enough, then this process could be divergent, causing a local pressure rise, resulting in the destruction of the beam.

For any beam tube, warm or cold, the equilibrium pressure becomes very large when

$$I > I_{crit} = \frac{S}{k\eta} \tag{1}$$

where S is the local pumping speed, k is a constant that contains the geometry, the molecular velocity, the ionization cross section, etc., and η is the desorption coefficient,

$$\eta = \frac{\text{Number of molecules out} - \text{Number of ions incident}}{\text{Number of ions incident}}$$

It is clear that for a warm bore machine, where the pumping speed is small, it is necessary to condition the beam tube to reduce η to values near unity. This approach has worked very well at the ISR. For a cold beam tube, the pumping speed is very high due to the sticking of molecules to the wall. On the other hand, measurements indicate that the desorption coefficient is extraordinarily large, particularly for wall coverages of a few monolayers of light gases, like hydrogen or helium[1,2]

II. Cold Bore Calculation

The condition for a pressure divergence in a cryogenic beam tube is[3]

$$I > I_{crit} = \frac{\pi r}{2}\frac{e\bar{v}s}{\sigma\eta} \tag{2}$$

where r is the beam tube radius, $\bar{v}$ is the average velocity of molecules desorbed from the walls, s is the probability that those molecules will stick to the walls on the first collision, σ is the ionization cross section for protons incident on the molecules, and η is the desorption coefficient. The velocity of desorbed molecules is not well known, and could vary from thermal velocities to a few electron volts. In the higher ranges, energy conservation limits the maximum value of η. The sticking probability is assumed to be near unity for thermal energies of molecules, slowly decreasing with increasing molecular energies. The desorption coefficient is a function of the wall coverage, t, and the incident ion energy E_I. For coverages of up to five monolayers and energies up to a few thousand electron volts, η can be approximated by $\eta \simeq E_I t$, with E_I in electron volts and t in monolayers. The ionization cross section for relativistic protons on a gas of atomic number Z is calculated to be $\sigma \simeq 2\times10^{-19}\, Z\ \text{cm}^2$.

The energy of the incident ions can be calculated for various beam parameters. The potential of the beam relative to the wall is

$$V_{beam} = \frac{\lambda}{2\pi E_0}\,\ell n\,\frac{r}{a} \tag{3}$$

for beam tube radius r (assumed to be 2.54 cm), beam radius a (taken as $\sigma \simeq [\varepsilon\bar{\beta}/6\pi]^{\frac{1}{2}}$, ε the emittance for 95% of the beam), and linear charge density λ. Table I shows the maximum voltage that an ion can have for a 20 TeV beam with a luminosity of 10^{33} cm^{-2} sec^{-1}, β^* = 2 meters at the interaction points, a bunch length of 20 cm, at two different invariant emittances, and three different bunch spacings. The average lattice function is taken to be $\bar{\beta}$ = 300 meters. In fact, in the bunched beam case the ions (assumed to be hydrogen)

TABLE I

Ion energy for various beam parameters with $\mathcal{L} = 10^{33}$ cm^{-2} sec^{-1}, β^* = 2 m, E_p = 20 TeV, and bunch length = 20 cm.

Bunch Spacing	Invariant Emittance (95%)	Protons per Bunch	T_I (Max)	T_I (Impulse)	Total Beam Current
10 m	$5\pi\times10^{-6}$ m	1.9×10^{10}	1.7 KeV	0.54 KeV	0.091 amps
10 m	$20\pi\times10^{-6}$ m	3.7×10^{10}	2.9 KeV	0.50 KeV	0.178 amps
30 m	$5\pi\times10^{-6}$ m	3.2×10^{10}	2.8 KeV	1.54 KeV	0.051 amps
30 m	$20\pi\times10^{-6}$ m	6.4×10^{10}	5.0 KeV	1.50 KeV	0.102 amps
100 m	$5\pi\times10^{-6}$ m	5.9×10^{10}	5.2 KeV	5.20 KeV	0.028 amps
100 m	$20\pi\times10^{-6}$ m	1.2×10^{11}	9.4 KeV	5.30 KeV	0.056 amps

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never have the maximum energy, because the beam bunch passes before the ion fully accelerates. Also shown is the energy gained in the impulse approximation. In the case of the closest bunch spacing, the subsequent bunch passage increases the ion energy by about 10% and is ignored.

Using the results of the impulse approximation, the desorption coefficient can be estimated for each bunch spacing, assuming various average molecular velocities and sticking probabilities. These are shown in Table II, for the same machine assumptions as in Table I, assuming 10 monolayers of free hydrogen on the walls. This is a very conservative estimate since there will be much less hydrogen or helium than that, and the desorption of heavier molecules is much lower. For average molecular energies above 0.1 eV, the desorption coefficient must decrease due to energy conservation, and the resultant critical current increases.

III. Conclusions

Comparing the calculated critical currents shown in Table II with the operating currents shown in Table I, it appears that in all cases there is at least an order of magnitude safety factor. Experiments done at the ISR[4] with a cold bore section indicate that the theory is probably conservative, so that it gives a value of the critical current less than the actual value. Experience at the Tevatron, where there have been a few long storage experiments, but no systematic study of the pressure bump phenomenon, indicate no problems so far. That probably means that there are no significant helium leaks into the beam tube, and that cryopumping of hydrogen from the warm sections is not a problem.

References

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TABLE II

Critical currents for three bunch spacings and three molecular energies

Bunch Spacing	η	I_{crit} (amps)	I_{crit} (amps)	I_{crit} (amps)
		E_{mol} = 4.5K S = 1.0	E_{mol} = 300K S - 0.7	E_{mol} = 0.1 eV S = 0.1
10 m	5,000	6.8	39	11.2
30 m	15,000	2.3	13	3.7
100 m	50,000	0.68	3.9	1.1